

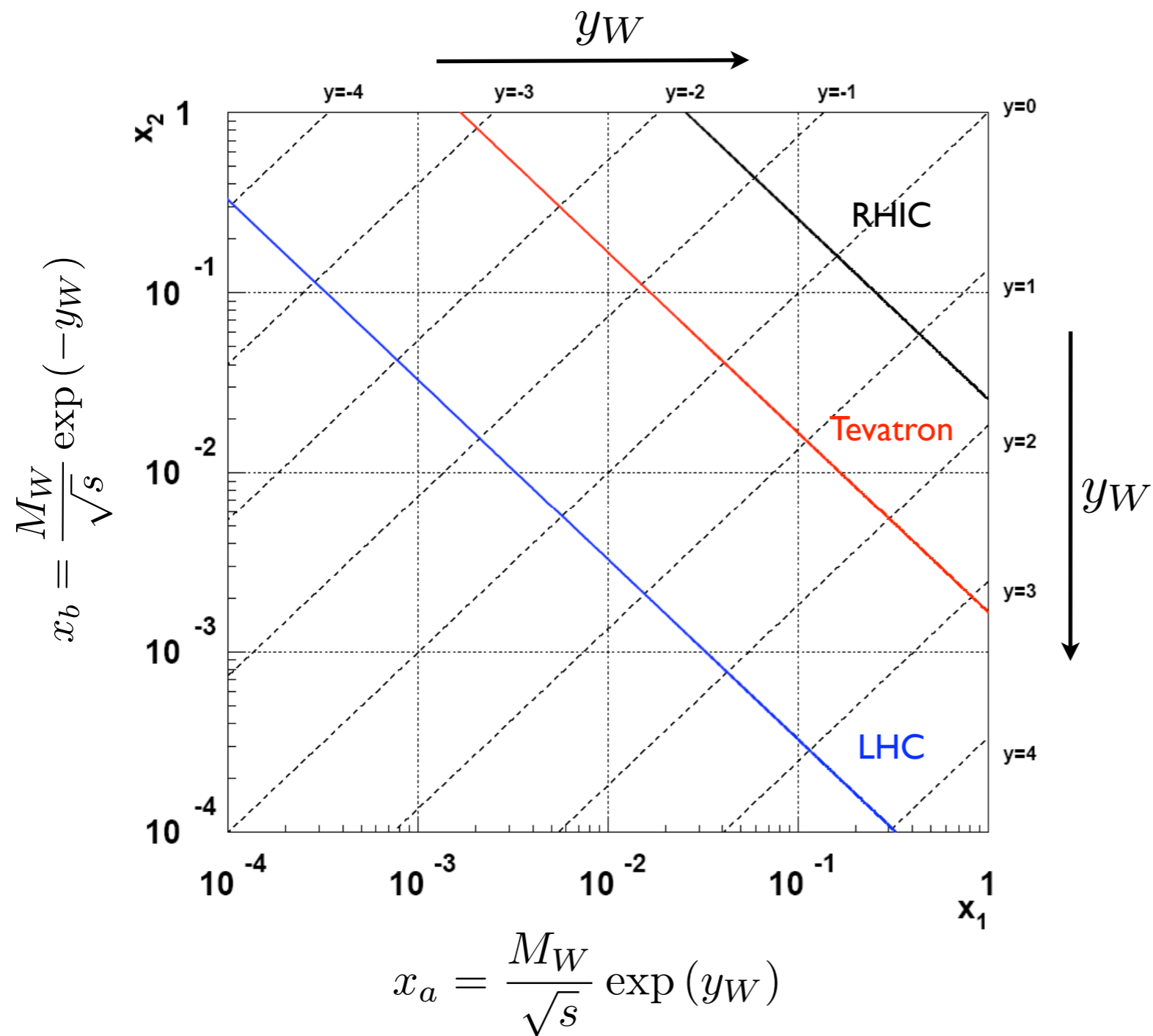
# Spin Physics with $W$ 's at RHIC

Ernst Sichtermann, *for the STAR and Phenix Collaborations*



- Introduction and Motivation
- RHIC: *new opportunities to study spin and* QCD
- Experiment: Challenges, Needs, and Sensitivity
- Summary and Outlook

# W's and PDFs at Colliders



$$pp \rightarrow u, \bar{d} \quad \bar{u}, d$$

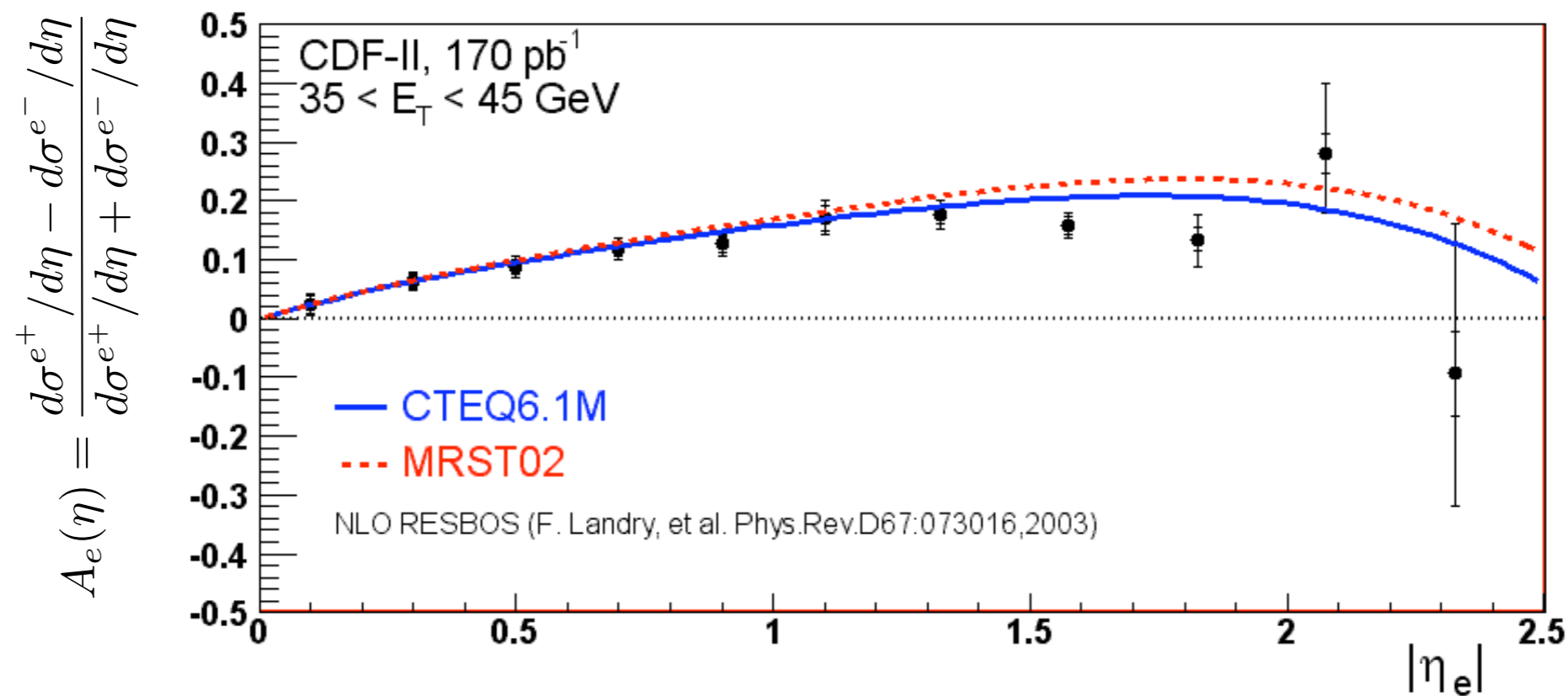
$$p\bar{p} \rightarrow u, d$$

# W's and PDFs at Colliders

A prime example is the Forward-Backward Charge Asymmetry,

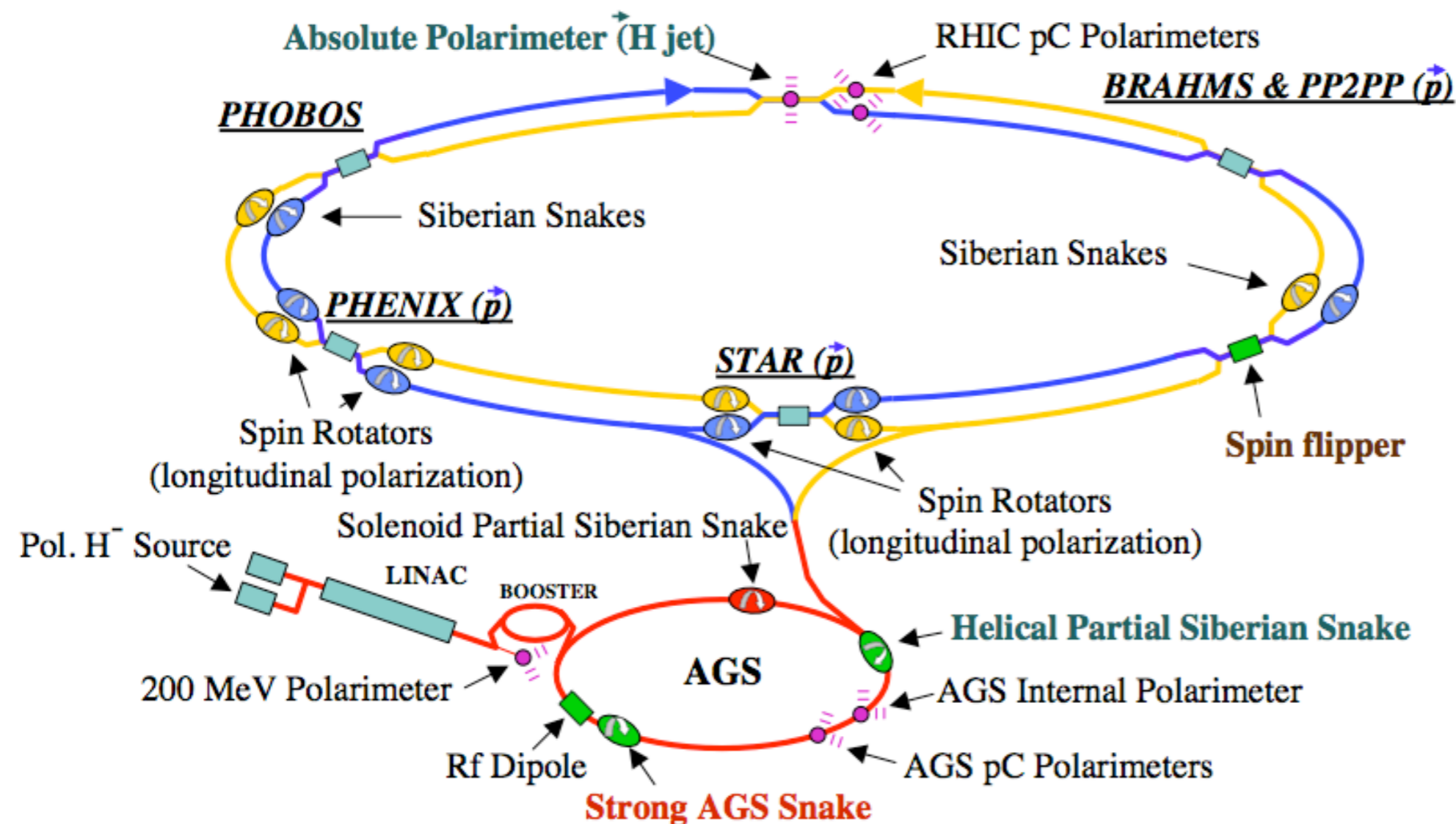
$$A(y_W) = \frac{d\sigma^{W^+}/dy_W - d\sigma^{W^-}/dy_W}{d\sigma^{W^+}/dy_W + d\sigma^{W^-}/dy_W} \simeq \frac{u(x_a)d(x_b) - d(x_a)u(x_b)}{u(x_a)d(x_b) + d(x_a)u(x_b)}$$

which is sensitive to u/d.



- + hard scale,
- + convolution with V-A decay,
- + theory under control - analysis beyond NLO,
- + sensitive to u/d, albeit at large |rapidity|

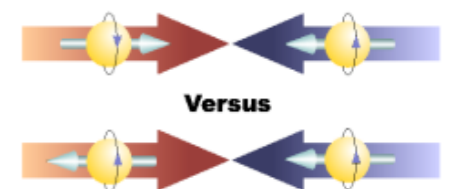
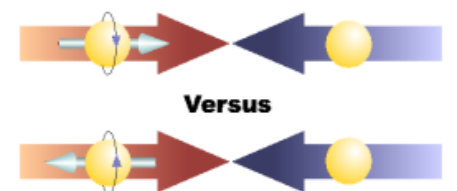
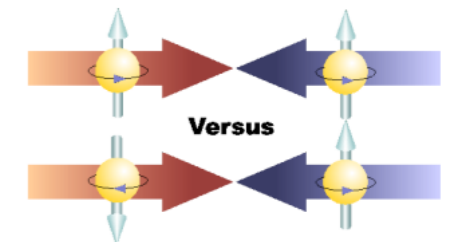
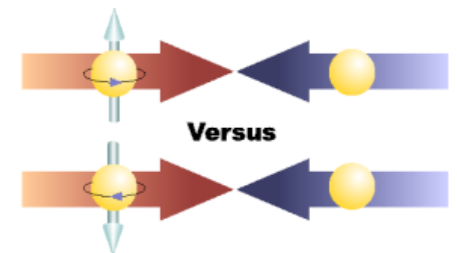
# RHIC - a new laboratory for studying spin in QCD



c.f.: W. Fischer, *RHIC Upgrades for Heavy Ions and Polarized Protons*, section XII.1

Measurements of:

proton – proton

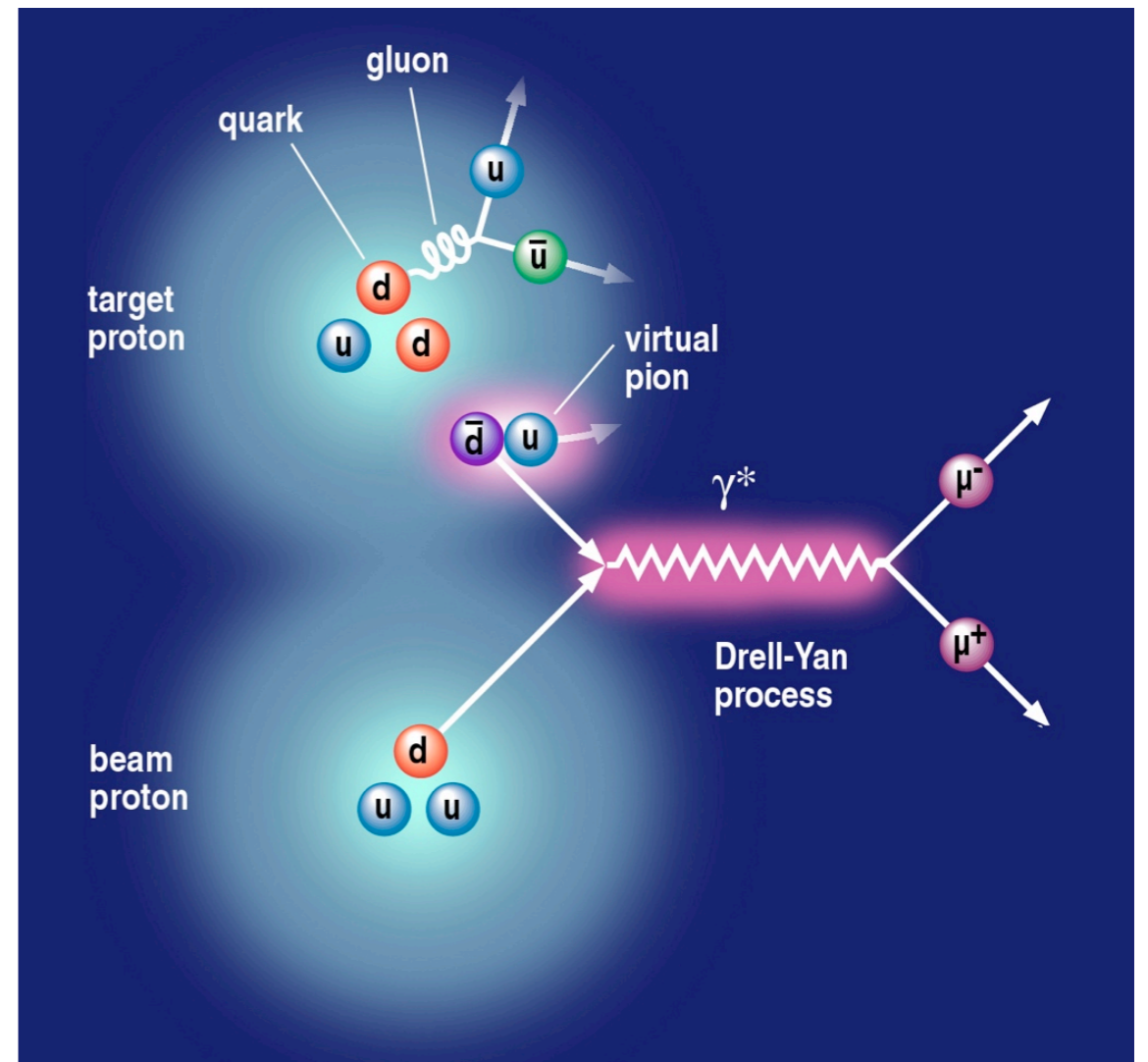
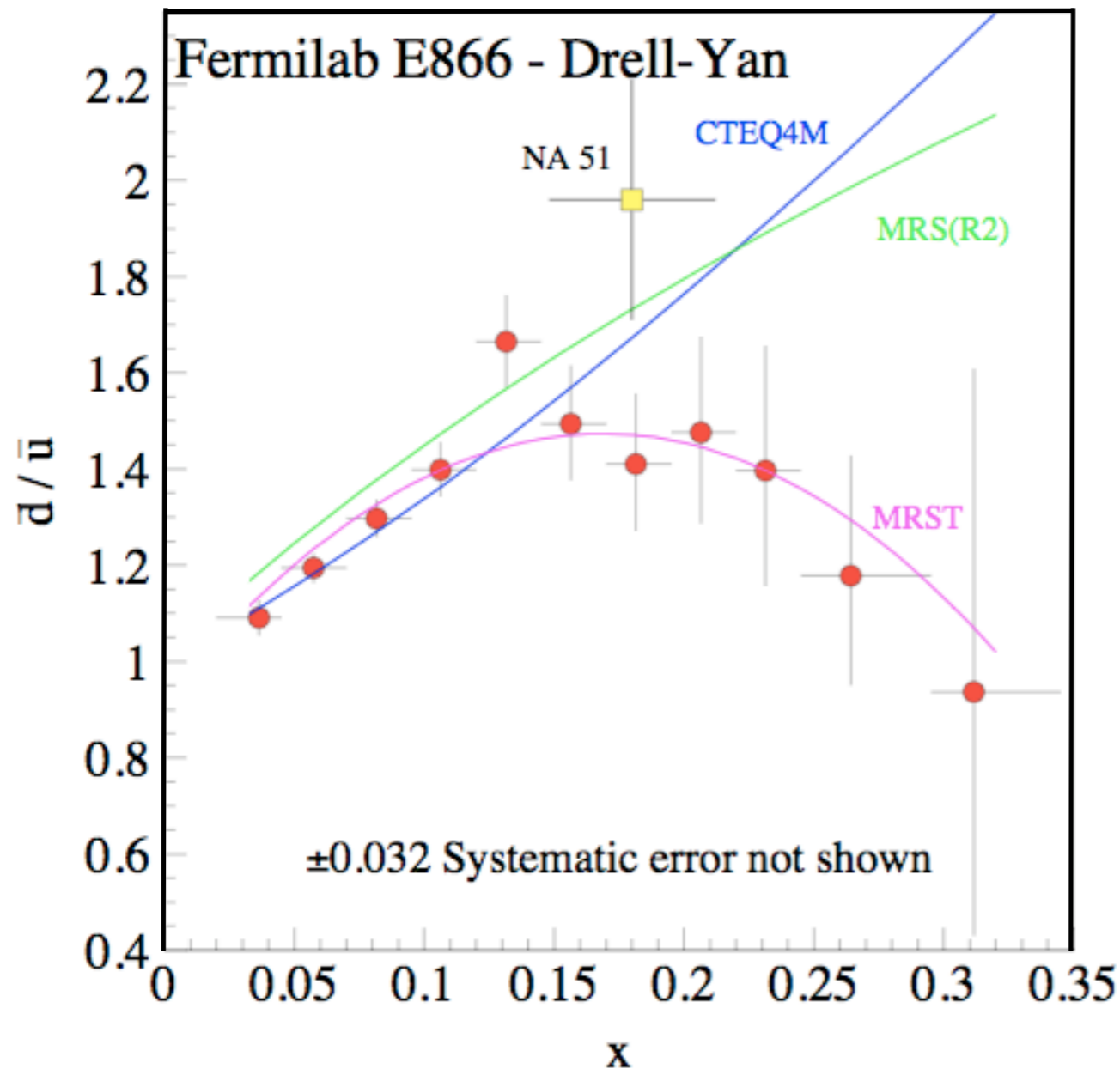


$\sqrt{s} = 200 - 500 \text{ GeV}$

- 2002-4: Engineering runs       $200\text{GeV}$ ,  $< 1\text{pb}^{-1}$ ,  $P \sim 40\%$  }  $A_{LL}$ ,  $\Delta G$  J. Kiryluk section III.2, K. Boyle section III.4
- 2005:      1 wk pp physics run  $200\text{GeV}$ ,  $\sim 3\text{pb}^{-1}$ ,  $P \sim 45\%$  }
- ...      + *successful first fills at 410GeV!*
- 2009:       $200\text{GeV}$  Physics complete ( $\sim 320\text{pb}^{-1}$ ,  $P \sim 70\%$ ) start of  $500\text{GeV}$  ( $800\text{pb}^{-1}$ ,  $P \sim 70\%$ )

# What is the (anti-)Flavor Composition of the Nucleon Spin?

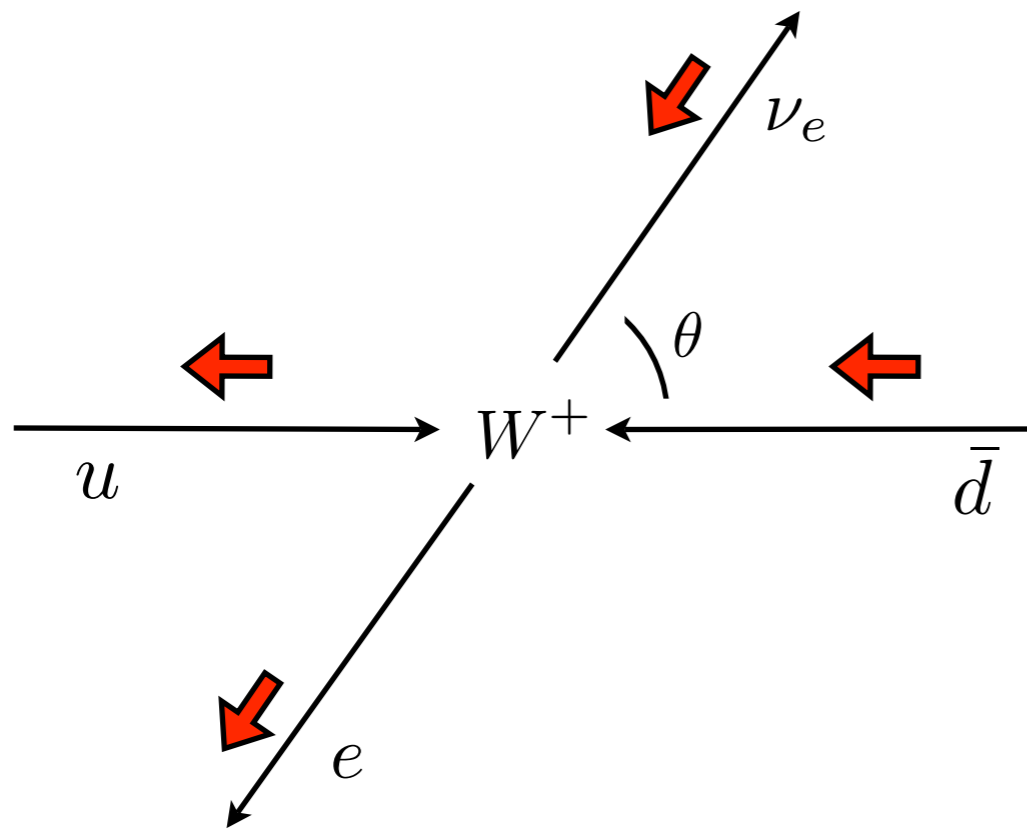
Clues from the unpolarized nucleon,



non-perturbative - very clear *need to measure*  $\Delta\bar{u}, \Delta u, \Delta\bar{d}, \Delta d$

**Note:**  $R_W(y, M_W^2) = \frac{\sigma^{W^+}}{\sigma^{W^-}} = \frac{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)}, \quad x \simeq 0.15 \text{ at midrapidity} \quad \text{from RHIC (?)}$

# W-bosons as Polarimeters



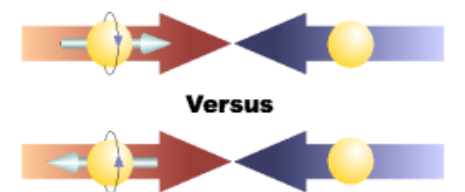
**Experiment Signature:**  
large  $p_T$  lepton, missing  $E_T$

$$\Delta\sigma^{\text{Born}}(\vec{p}p \rightarrow W^+ \rightarrow e^+ \nu_e) \propto -\Delta u(x_a)\bar{d}(x_b)(1+\cos\theta)^2 + \Delta\bar{d}(x_a)u(x_b)(1-\cos\theta)^2$$

**Spin Measurements:**

$$A_L(W^+) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)} = \begin{cases} -\frac{\Delta u(x_a)}{u(x_a)}, & x_a \rightarrow 1 \\ \frac{\Delta\bar{d}(x_a)}{\bar{d}(x_a)}, & x_b \rightarrow 1 \end{cases}$$

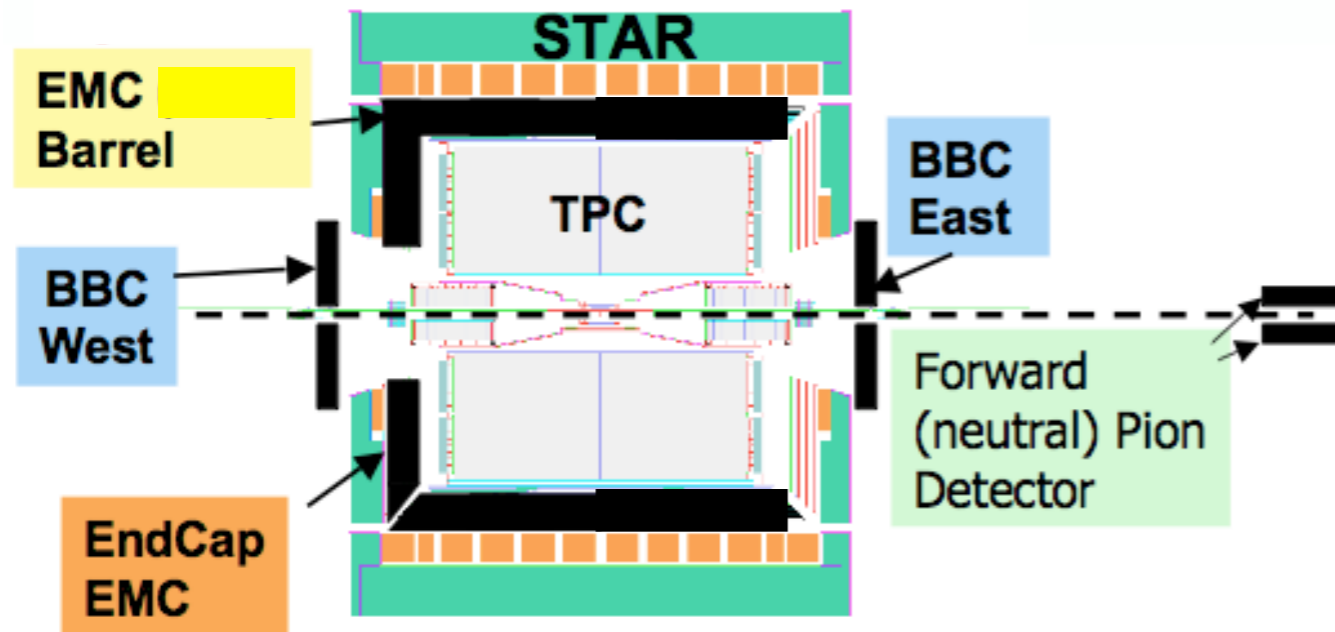
$$A_L(W^-) = \begin{cases} -\frac{\Delta d(x_a)}{d(x_a)}, & x_a \rightarrow 1 \\ \frac{\Delta\bar{u}(x_a)}{\bar{u}(x_a)}, & x_b \rightarrow 1 \end{cases}$$



**charge-ID at large |rapidity|!**

# Experiment, Challenges, Needs, and Sensitivity

STAR:

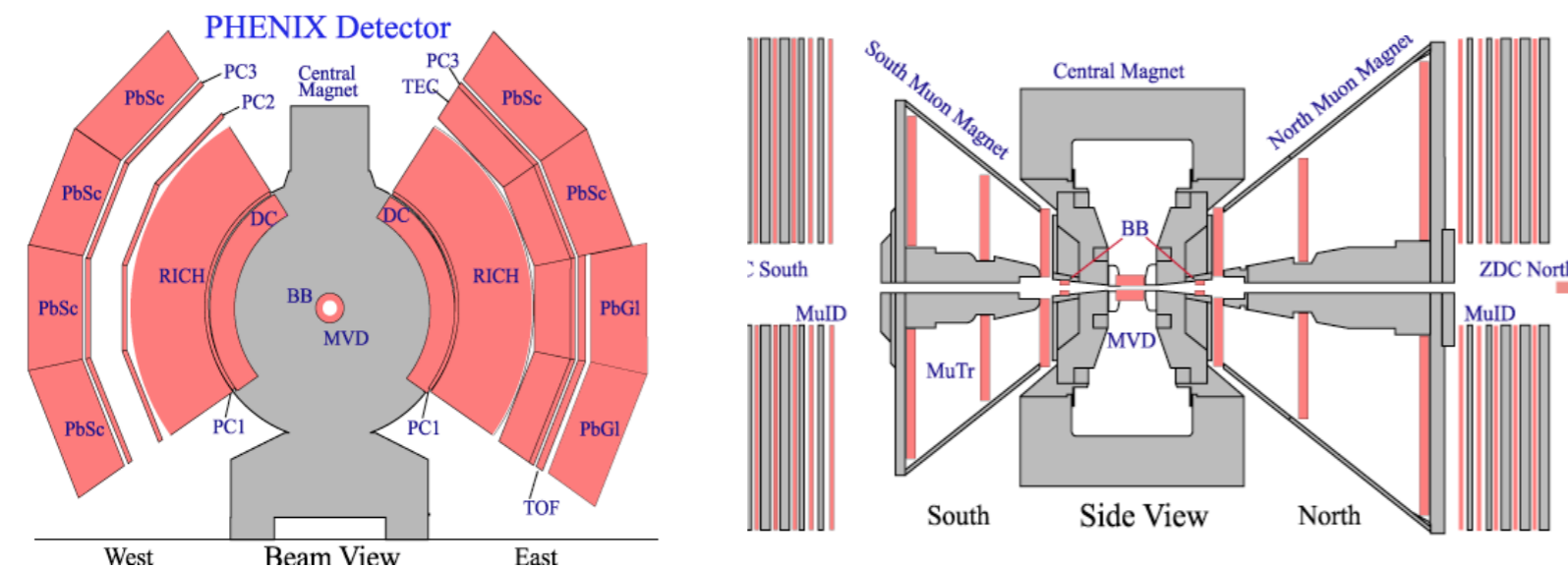


STAR Measurements:

$$-1 < \eta < 2, \quad \Delta\phi = 2\pi, \quad \text{electron}$$

Phenix:

Phenix Measurements:



$$\text{central arm } |\eta| < 0.35, \quad \Delta\phi = \pi, \quad \text{electron}$$

$$\text{muon arm } 1.2 < |\eta| < 2.4, \quad \Delta\phi = 2\pi, \quad \text{muon}$$

# Experiment, Challenges, Needs, and Sensitivity

- Charge-ID at large |rapidity|
- Suppression of charged hadron background:

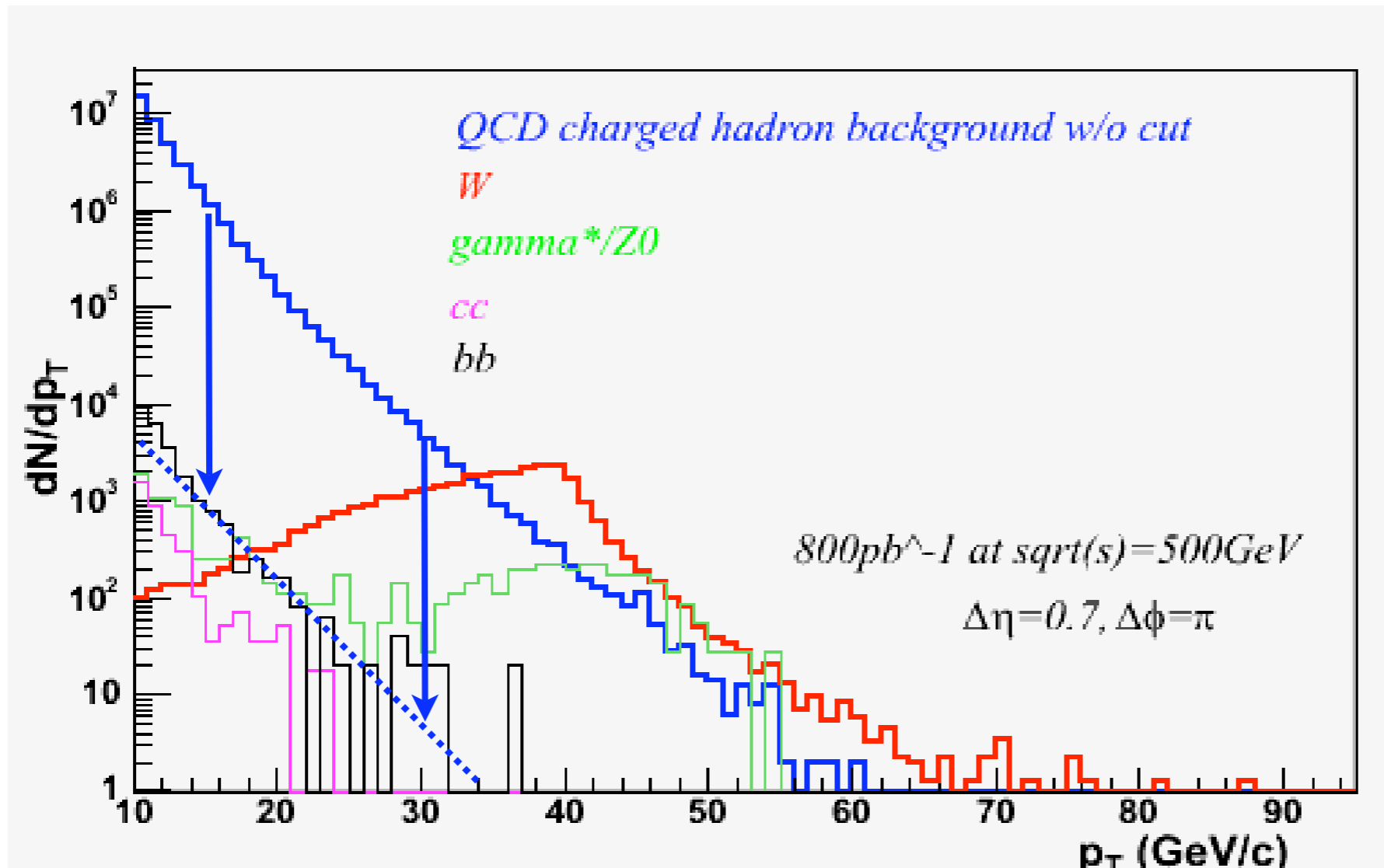


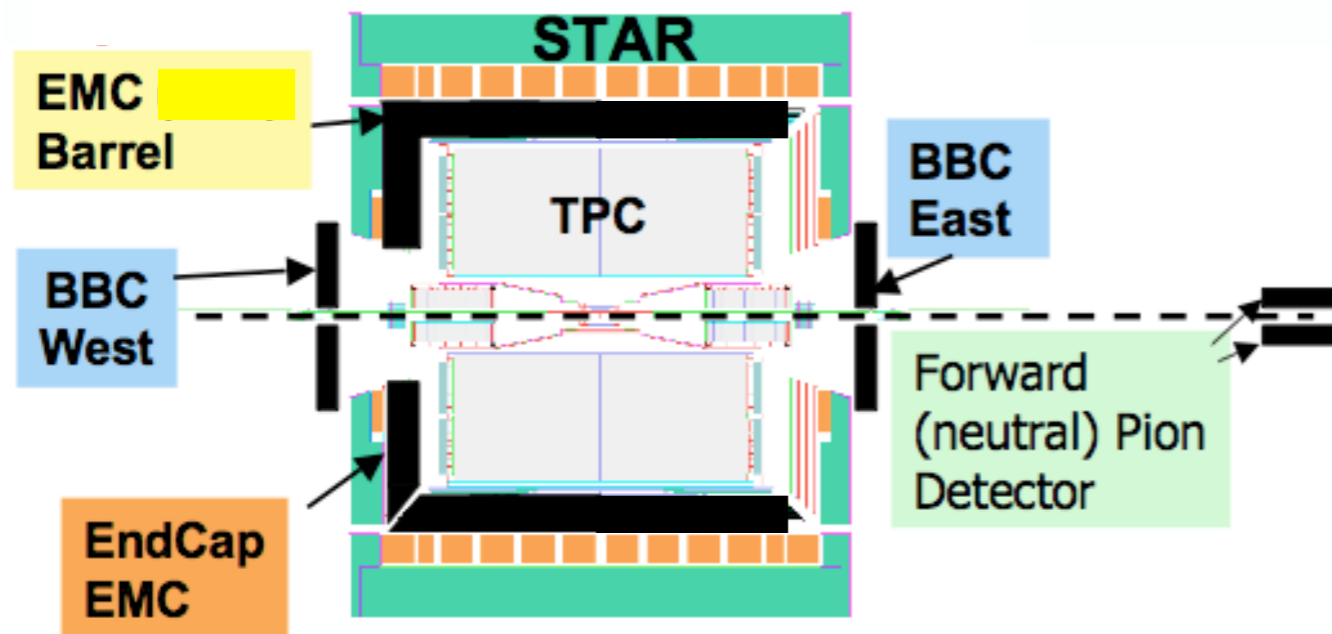
Illustration for Phenix Central Region, similar for STAR.

Need  $\sim 10^3$  suppression of charged hadrons to make a  $p_T > 20$  GeV/c measurement possible,

Remaining Z background may allow measurement of charge-ID efficiency.

# Experiment, Challenges, Needs, and Sensitivity

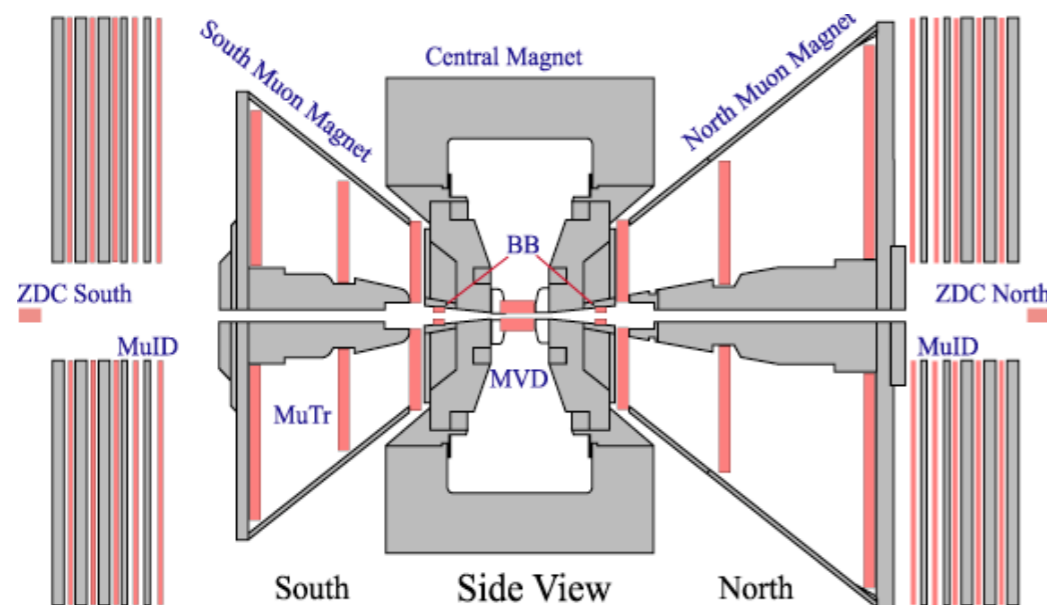
STAR:



E/p selection	~10,
Isolation	~10,
Missing $E_T$	~10,
Longitudinal shower profile	<hr/> $> 10^3$

TPC tracking breaks down in forward region,  
i.e. need **forward tracking upgrade**.

Phenix (focussing on the muon arms):

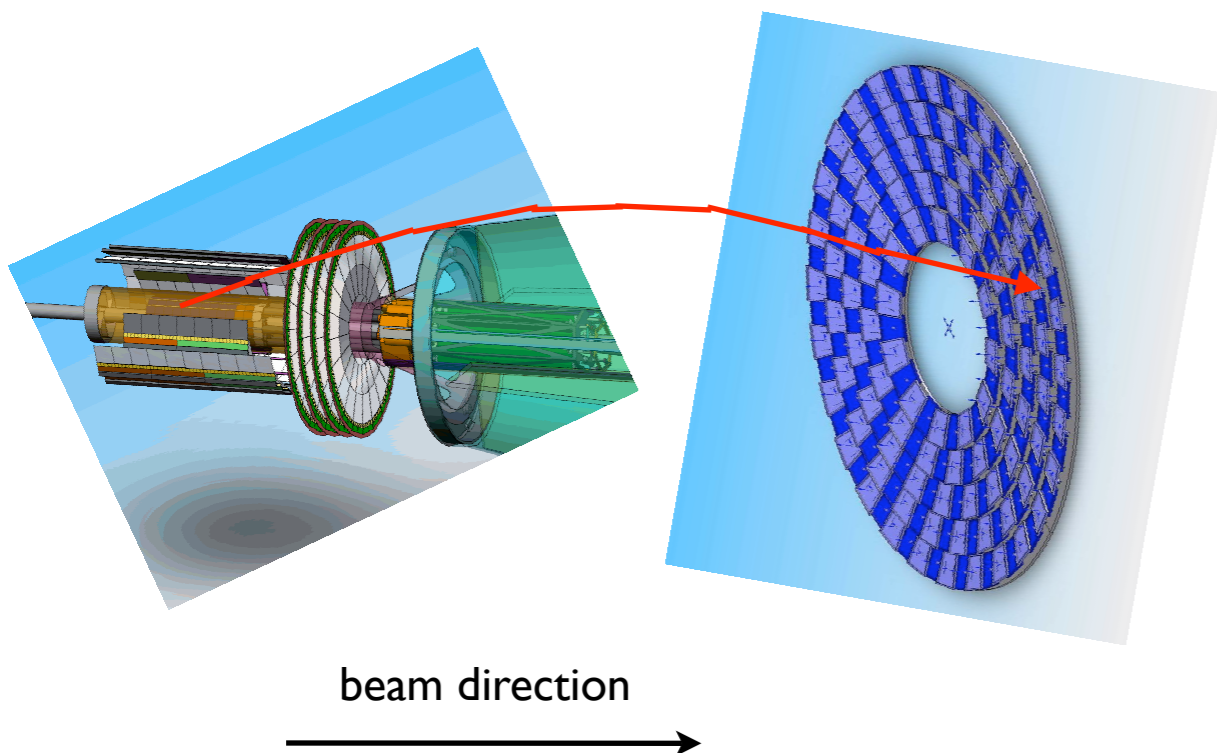


Absorber	~100,
Isolation	~ 5,
Shower profile	
$m_T$ with nose-cone cal.	<hr/> $> 5 \cdot 10^2$

~12MHz collision rate, ~10kHz bandwidth,  
i.e. need **muon trigger upgrade**.

# Experiment, Challenges, Needs, and Sensitivity

STAR (not to scale):



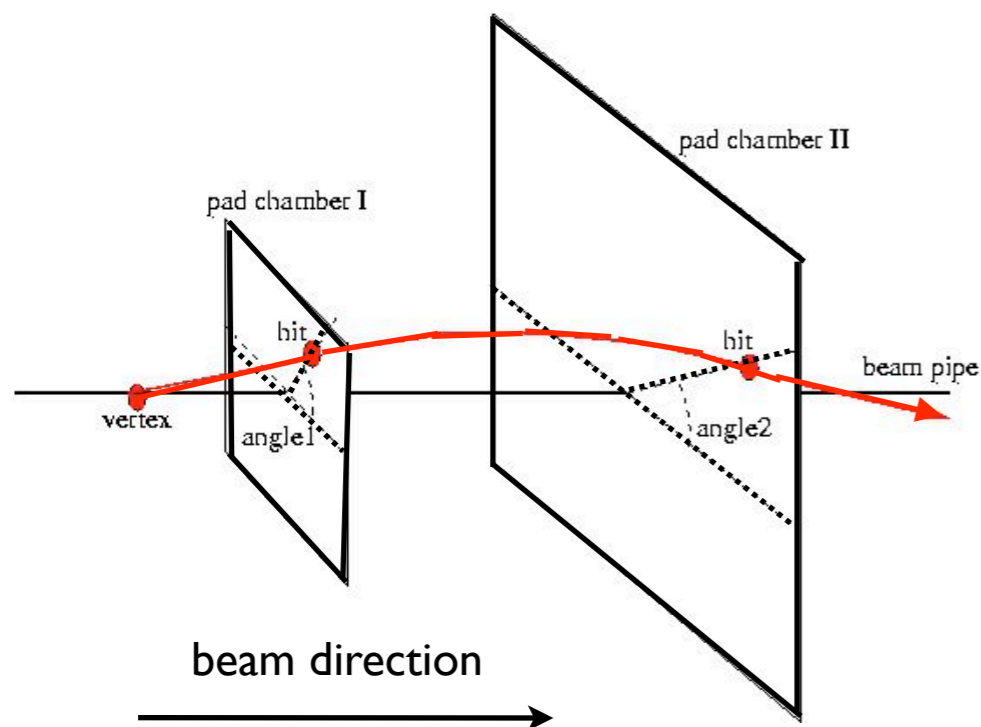
*Current technology choice:*

Forward Silicon Strip Disks,  
GEM Endcap Calorimeter Tracker,

Participation: MIT, LBNL, Yale, ANL, BNL,  
IUCF, Zagreb

DoE Proposal 2006

Phenix:



*Technology choice:*

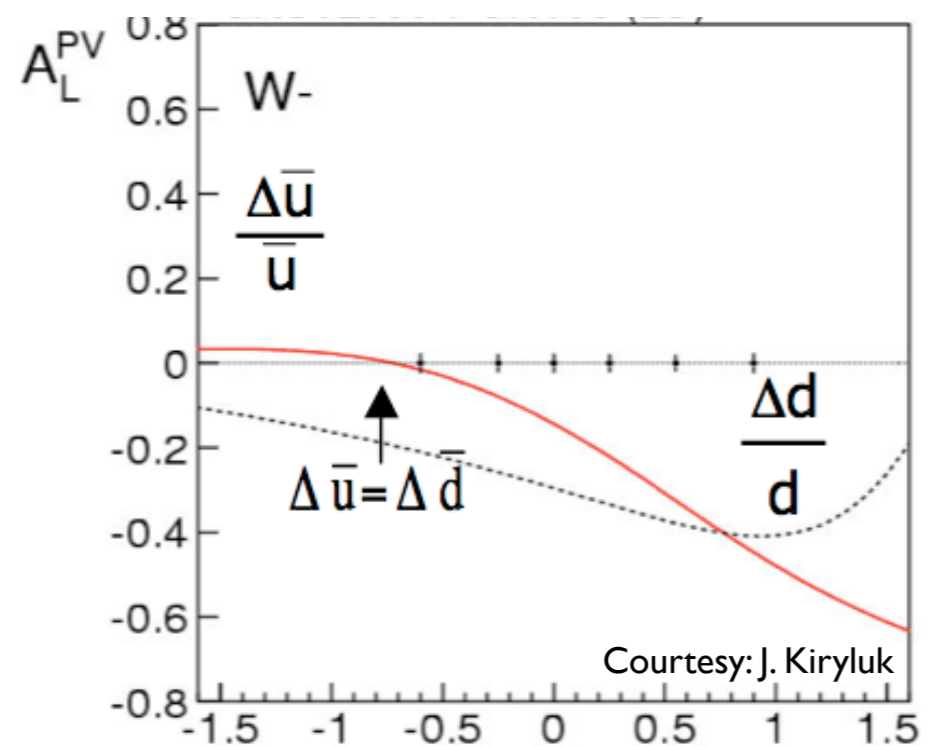
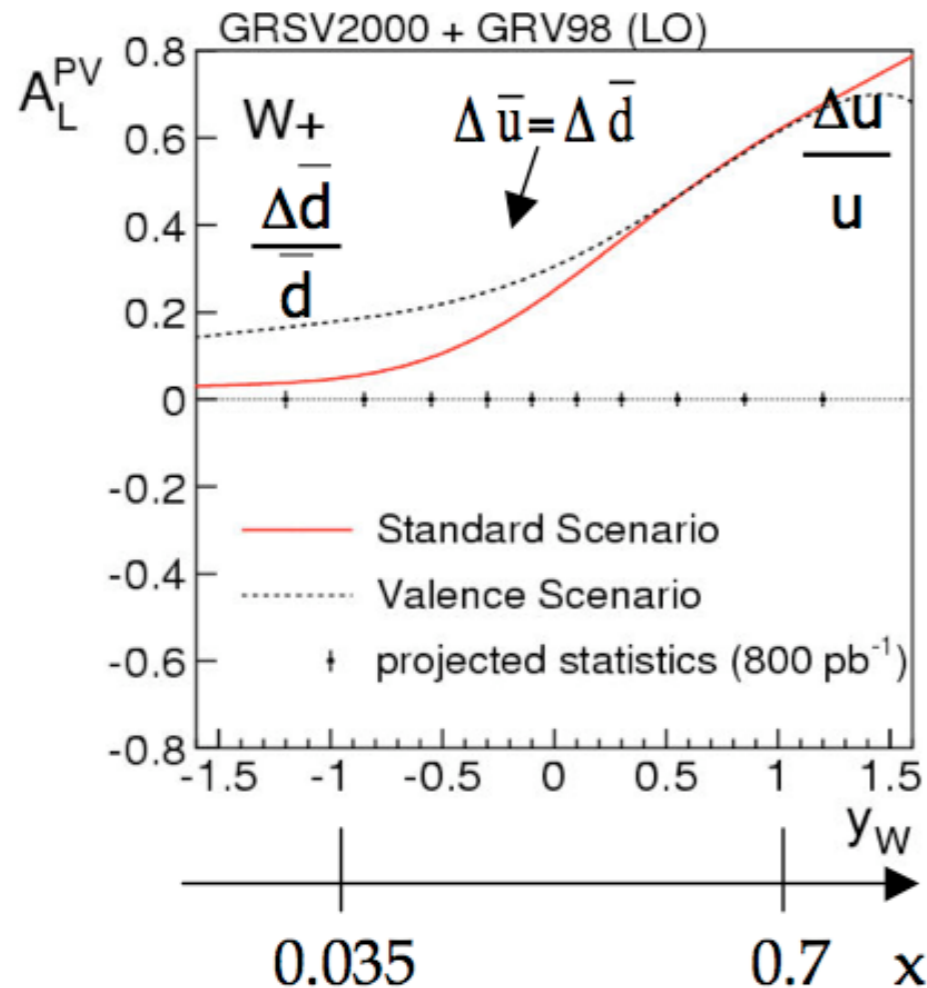
Resistive Plate Chambers  
Fast Front-End Electronics

Kyoto, RBRC, UC-Riverside, UIUC, ...

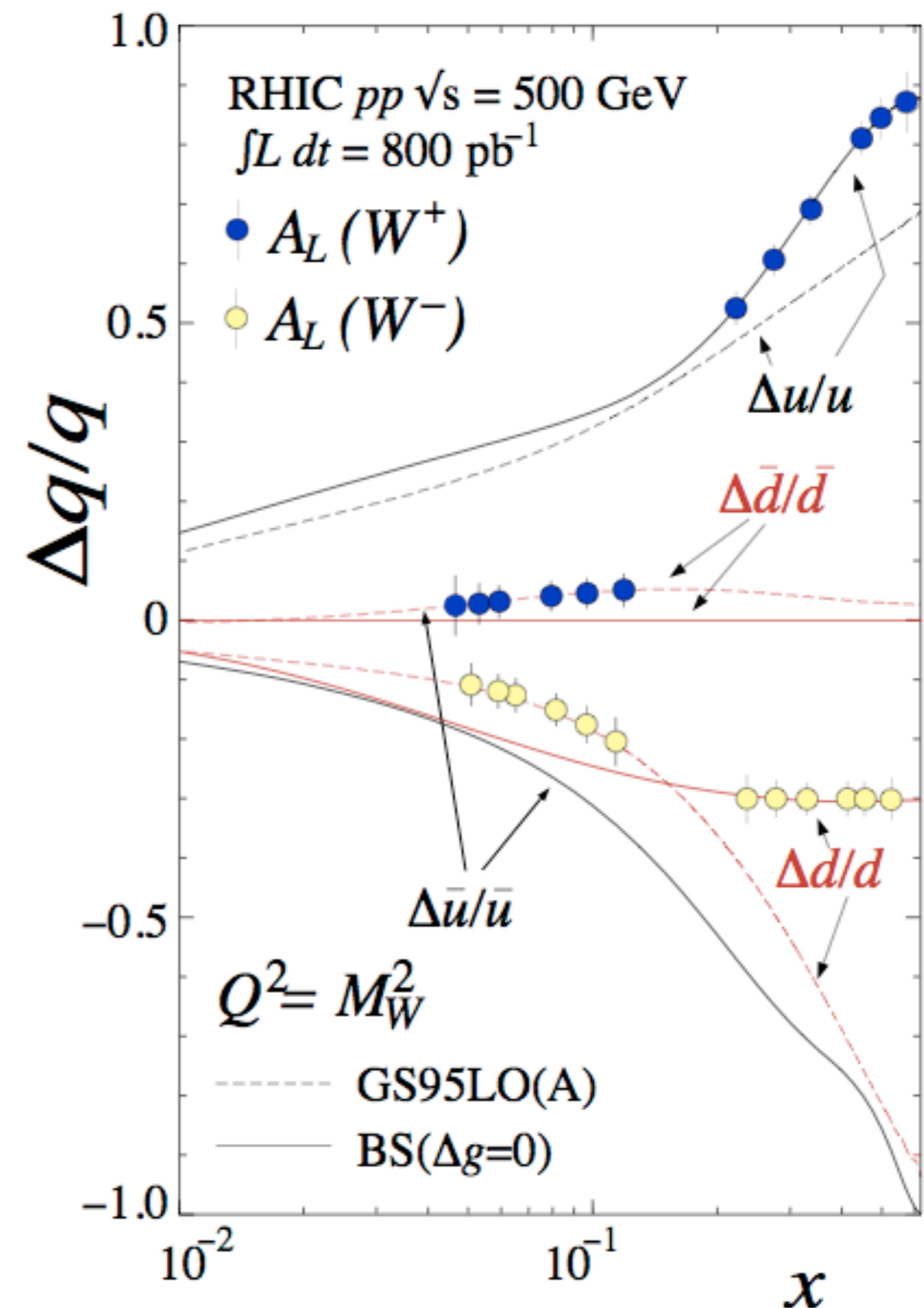
NSF and other proposals, completion 2009<sub>11/13</sub>

# Experiment, Challenges, Needs, and Sensitivity

STAR:



Phenix:



Courtesy: N.Saito

# Summary and Outlook

- RHIC pp at 500 GeV opens *new* channels to study spin and **QCD**,
- Leptonic W decays:
  - + hard scale (W-mass),
  - + convolution of W production with V-A decay,
  - + theory under control - analyses beyond NLO,
  - + sensitivity complementary to and eventually surpasses SIDIS
- Needs:
  - upgrades (relatively modest) to Phenix and STAR,
  - continued machine development - success in 2005: 410 GeV, high integrated luminosity
- I look forward to 500GeV *running* soon, opportunities with hadronic W, Z decays (?) while machine performance is developed.
- RHIC's impact on PDFs has come online, see e.g. posters by J.Webb (STAR EndCap  $\pi^0$ ), J.Seele (Phenix  $\eta$ ), talk by Q.Xu (STAR  $\Lambda, \bar{\Lambda}$ ) in section III.7, S.Heppelman (STAR transverse) in section III.6, and others - in addition to  $A_{LL}$  (STAR jets, Phenix  $\pi^0, J/\psi$ ).